Mitosis, Meiosis and Fertilization
– Major Concepts, Common Misconceptions and Learning Activities

Dr. Ingrid Waldron, Department of Biology, University of Pennsylvania, 2015[1]

Major Concepts and Common Misconceptions

Major Concepts:

- Mitosis is a type of cell division that produces two genetically identical diploid daughter cells. Mitosis produces new cells for growth and repair. Mitosis produces all the cells in our body except sperm and eggs.
- To ensure that each daughter cell receives a complete copy of the DNA in the parent cell, the DNA in each chromosome is replicated, and then the two copies of each chromosome are separated into two genetically identical daughter cells.
- A different type of cell division, called meiosis, produces haploid gametes (sperm and eggs).
- After the DNA is replicated, the first meiotic cell division separates each pair of homologous chromosomes and the second meiotic cell division separates the sister chromatids of each chromosome.
- Different gametes produced by the same person have different genetic makeup due to the separation of homologous chromosomes with different alleles into different gametes, independent assortment and crossing over.
- A haploid sperm fertilizes a haploid egg to produce a diploid zygote which has received half of its genes from the father and half from the mother. The zygote undergoes repeated mitosis to produce an embryo and ultimately a baby.
- As a result of meiosis and fertilization, each offspring has half of his/her genes from his/her mother and half from his/her father. As a result, children tend to resemble their parents and their siblings. However, the genetic diversity of the sperm and eggs results in genetic diversity of the different offspring produced by the same mother and father.

It is important to begin by focusing on these major concepts to ensure that students understand the basics and have a meaningful context for understanding the specifics of mitosis and meiosis. The approach to teaching mitosis and meiosis suggested below is designed to accomplish this goal and to help students overcome the following common misconceptions: [2]

- Students have difficulty distinguishing between mitosis and meiosis and between somatic and germ lines.
- Students don't understand the role that meiosis plays in heredity (e.g. why offspring resemble their parents and why there are genetic differences between siblings).
- Students do not understand the role of chance in producing new heritable characteristics by forming new combinations of existing genes… Sexual reproduction is not recognized as a source of variation.
- In general students do not appreciate the chemical basis of inheritance.

[1] These Teacher Notes and multiple activities for teaching biology are available at http://serendip.brynmawr.edu/exchange/bioactivities.

[2] These misconceptions are paraphrased from a useful discussion of key concepts, common misconceptions, and learning activities for meiosis and variation in Chapter 3 of Hard to Teach Biology Concepts by Susan Koba with Ann Tweed, 2009, NSTA Press.

Suggested Sequence of Learning Activities

This suggested sequence of learning activities is based on two related hands-on, minds-on modeling activities:

- **Mitosis – How Each New Cell Gets a Complete Set of Genes** (Student Handout and Teacher Preparation Notes available at http://serendip.brynmawr.edu/exchange/waldron/mitosis)
- **Meiosis and Fertilization – Understanding How Genes Are Inherited** (Student Handout and Teacher Preparation Notes available at http://serendip.brynmawr.edu/exchange/waldron/meiosis)

These activities are aligned with the Next Generation Science Standards (as explained in the Teacher Preparation Notes). The Teacher Preparation Notes also provide learning goals, instructional suggestions and biology background. These activities are part of an integrated sequence of learning activities for teaching genetics, presented in "Genetics – Major Concepts and Learning Activities" (available at http://serendip.brynmawr.edu/exchange/bioactivities/GeneticsConcepts).

We offer both a more complete version of the Student Handout for each of these activities (primarily for use with high school students) and a shorter version (primarily for use with middle school students). The question numbers and page numbers cited below refer to the more complete version of the Student Handout.

Introduction

- Begin with motivational discussion: understanding mitosis, meiosis and fertilization helps us to understand the causes of Down syndrome and the inheritance of genetic conditions such as albinism, sickle cell anemia and sensitivity to alcohol (all of which are discussed in the hands-on modeling activities; background information is provided in the Teacher Preparation Notes for these activities).

- Probe Questions: What are genes? What are chromosomes? What is DNA? What are proteins?
    - Discussion of probe questions will get students thinking about the topic; research evidence indicates that students learn better if they began thinking about the question as the initial phase of learning. Probe questions also help the teacher understand what students already know and what misconceptions will need to be addressed.
    - If appropriate, review the functions of proteins and genes in DNA, e.g. using "Understanding the Functions of Proteins and DNA" (available at http://serendip.brynmawr.edu/exchange/bioactivities/) which provides learning activities to help students understand how genes cause albinism, sickle cell anemia, hemophilia, alcohol sensitivity, and lactose intolerance.
    - Review chromosomes and genes using page 1 and the top of page 2 in the Student Handout for the mitosis activity.
    - To maximize student learning, I recommend that you have students answer each group of related questions individually or in pairs, followed by a class discussion of these questions.

Mitosis

- Probe Question: How does each cell in the body get a complete set of chromosomes/genes/DNA?

During the discussion of this probe question it should be possible to elicit the following ideas from your students.

- Cells arise by one cell dividing into two cells.
- In preparation for cell division, the cell will need to make two copies of all of its DNA so each daughter cell can get one copy.
- The cell will need some way to separate the two complete copies of the DNA.

- Introduce mitosis (the bottom of page 2 through page 4 of the Student Handout for the mitosis activity).

- Show the short video on mitosis available at https://www.youtube.com/watch?v=VlN7K1-9QB0.

- Modeling Mitosis and questions (page 5-7 of the mitosis Student Handout)

- Return to Probe Questions: What are genes? What are chromosomes? What is DNA? How does each cell in the body get a complete set of chromosomes/genes/DNA? You may want to distribute copies of the figures shown on pages 6-7 of this document; students can work individually or in pairs to label the figures and provide explanations that answer the probe questions; then, have a class discussion of the students' answers.

Meiosis and Fertilization

- Probe Question: How does a baby get half of his/her genes from his/her mother and half of his/her genes from his/her father?

- Introduce meiosis using pages 1-2 of the Student Handout for "Meiosis and Fertilization – Understanding How Genes Are Inherited".

- Modeling Meiosis, including independent assortment, and analyzing crossing over to understand the reasons for genetic diversity of different gametes produced by the same person (pages 3-4 and the top of page 5 in the Student Handout)

- To consolidate and extend student understanding of meiosis, you may want to use one of these videos:
  - Meiosis (available at https://www.youtube.com/watch?v=D1_-mQS_FZ0; a brief, clear review of meiosis)
  - Meiosis: Crossing over and Variability (available at https://www.youtube.com/watch?v=rqPMp0U0HOA; this video includes a discussion of the contribution of independent assortment and crossing over to genetic diversity)
  - Meiosis: the Great Divide (available at https://www.youtube.com/watch?v=toWK0fIyFlY&list=PLwL0Myd7Dk1F0iQPGrjehze3eDpco1eVz&index=11; this video includes a clear basic introduction to the phases of meiosis I and meiosis II)

- Comparing Mitosis and Meiosis (questions 15-18 on pages 5-6 of the Student Handout); you may want your students to use the animation comparing mitosis and meiosis (click on launch interactive under How Cells Divide at http://www.pbs.org/wgbh/nova/body/how-cells-divide.html#).

- Analyzing Meiosis and Fertilization to Understand Inheritance (pages 6-8 of Student Handout)

- To help students consolidate their learning, revisit the probe question, "How does a baby get half of his/her genes from his/her mother and half of his/her genes from his/her father?" Then, have students explain why no two siblings inherit exactly the same combination of alleles from their parents (see question 25 in the more complete meiosis and fertilization Student Handout or question 21 in the shorter Student Handout and page 7 in the Teacher Preparation Notes). In preparation for this discussion, you may want to distribute copies of page 8 of this document and have students work individually or in pairs to respond to the questions.

- A Mistake in Meiosis Can Cause Down Syndrome (page 9 of the Student Handout for the meiosis and fertilization activity).

Suggested Follow-Up Activities

We recommend that this activity be followed by our **Genetics** activity, so your students will develop a better understanding of how meiosis and fertilization provide the basis for understanding inheritance.

(available at http://serendip.brynmawr.edu/sci_edu/waldron/#genetics)

This activity helps students to understand basic genetics concepts, including how genotype influences phenotype and how understanding meiosis and fertilization provides the basis for understanding inheritance. The modules in the Student Handout and Genetics Supplement include (1) an introductory module that uses the example of albinism to help students understand all of the basic concepts and introduces students to the Punnett square as a summary of how genes are transmitted from parents to offspring by the processes of meiosis and fertilization, (2) a Coin Toss Genetics activity and an analysis of student data on the sex makeup of sibships, both of which help students understand the probabilistic nature of inheritance and Punnett square predictions, (3) an analysis of the inheritance of sickle cell anemia that reinforces basic concepts and introduces the important points that a single gene often has multiple phenotypic effects and alleles are often neither completely dominant nor completely recessive, and (4) pedigree analyses for recessive and dominant alleles, including challenge questions that introduce the role of new mutations and engage students in evaluating the relative advantages and disadvantages of Punnett squares and pedigrees as models of inheritance.

These activities are part of an integrated sequence of learning activities for teaching genetics, presented in"Genetics – Major Concepts and Learning Activities" (available at http://serendip.brynmawr.edu/exchange/bioactivities/GeneticsConcepts).

Other Possible Follow-Up Activities

Mitosis and Meiosis Card Sort Activity

(available at http://serendip.brynmawr.edu/exchange/bioactivities/mmfcardsort)

This activity is designed to help students review the processes of mitosis and meiosis and to ensure that students understand how chromosomes move during mitosis vs. Peiosis. Students arrange the cards from a shuffled deck of the stages of mitosis and meiosis in the sequence of steps that occur during cell division by mitosis and another sequence of steps that occur during cell division by meiosis.

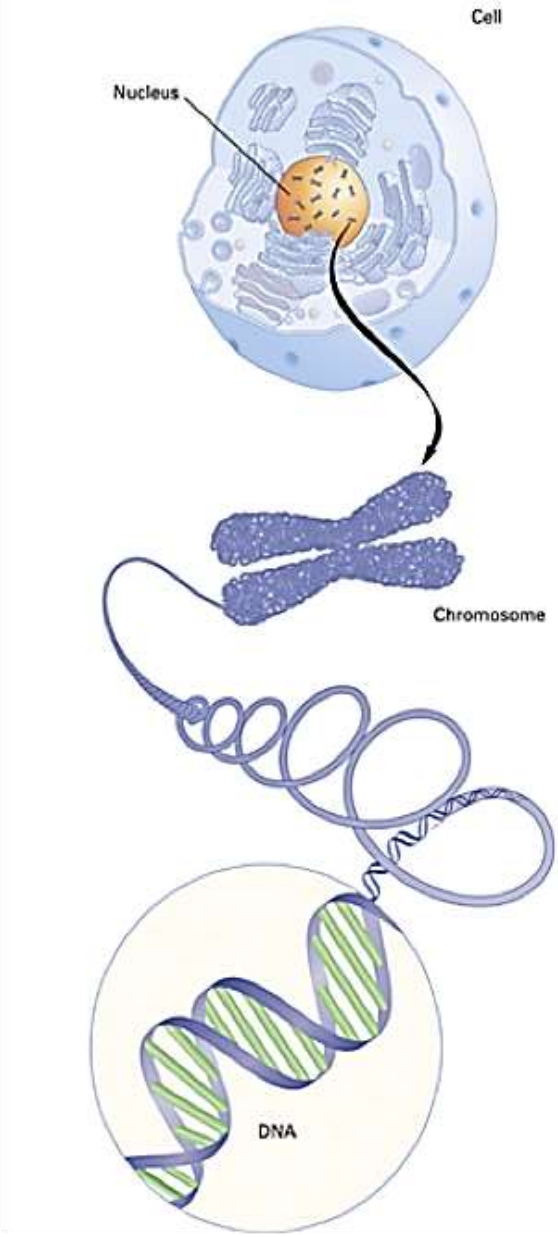
Mitosis, Meiosis and Fertilization Vocabulary Review Game

(available at http://serendip.brynmawr.edu/exchange/bioactivities/mmfvocabgame)

This game helps students to enjoy reviewing vocabulary related to mitosis, meiosis and fertilization. Many students have trouble learning the substantial new vocabulary required for biology, and this game is designed to allow students to have fun while reinforcing their understanding of key terms.

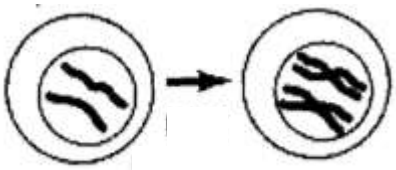
Write sentences and label the figures to answer these questions:

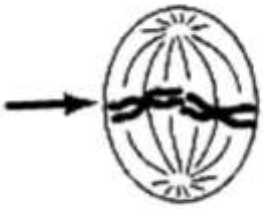
- What are chromosomes?
- What is DNA?
- What are genes?

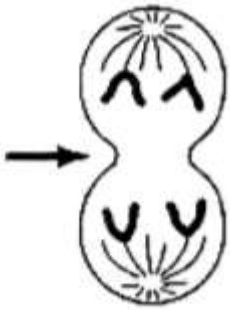


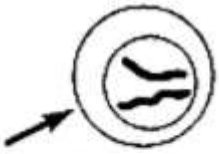
Write sentences and label the figures to answer the question:

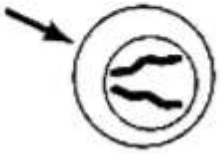
"How does each cell in the body get a complete set of chromosomes/genes/DNA?











Write sentences and label and add to the diagram to answer these questions:

- How does a baby get half of his/her genes from his/her mother and half of his/her genes from his/her father?
- Why don't any siblings (except identical twins) inherit exactly the same combination of alleles from their parents?